ARCHITECTURAL ACOUSTICS

By ARTHUR ELSON

THE velocity of sound in our atmosphere is about 1100 feet a second—more in warm weather, and less in cold. Sound travels via the "Air line;" that is, unless disturbed by reflectors or obstacles, it radiates outward from its source in straight lines, each particle of air being moved, and transmitting its motion to the next particle beyond it. Under these conditions the intensity of sound diminishes in proportion to the square of the distance it has travelled. In this respect it resembles light.

But while light is an imponderable vibration in the ether (if Einstein will let us keep the undulatory theory), sound waves are movements of actual matter. In this respect they have some analogy with ocean waves, and will follow curved surfaces in much the same way that the billows will wash up the slope of a shelving rock.

Sound has also the power of arousing sympathetic vibrations. The many resonators of Helmholtz, which he used to detect overtones, were antedated in principle by the hollow vessels placed here and there in the Greek or Roman theatres, to reinforce the speaker's voice.

All of these properties are employed in modern architecture, which is gradually mastering the rules of acoustics, and is becoming less of a hit-or-miss affair than it has been in previous centuries.

The chief obstacles to the best propagation of sound may be enumerated under five headings—natural diminution, absorption, obstruction, reverberation, and echo.

The first of these is the lessening of sound mentioned above, due to the increasing distance traveled. Thus at twice the distance from the speaker, the sound of his voice would seem only one-fourth as loud. This obstacle is encountered only in very large buildings, in which there is room for many devices that may aid the spread of sound and obviate this advantage.

Absorption takes place when there are large empty places above or behind the speaker. This is a negative rather than a positive action, and merely means that the building is not well

arranged to intensify the sound. A speaker in such a building is under much the same conditions as one who talks outdoors, in which case an ordinary voice is not clearly audible beyond sixty feet. For this reason the best concert-halls, and even churches, have performers' seats, or the pulpit, placed in a little recess, with a ceiling lower than that of the main building, and sloping upward as it extends forward. Theatres have somewhat the same structure, though there is no sloping ceiling over the stage.

A more real absorption of sound takes place when it encounters non-reflecting surfaces. Curtains, draperies, and even the clothing of the audience, are of this type. Every observant reader will know of cases in which the reverberation of a room or hall when empty would sound excessive, while the same structure when filled with furniture, or people, or both, would seem acoustically excellent. Usually there is an excess of such reverberation in public buildings, so that absorption becomes a benefit instead of a defect. For example, churches are very often improved by the use of matting or carpets on the floor. A similar treatment of floor and walls is often used to deaden sound in library reading-rooms. But in large halls, where power of tone is needed, the audience will produce all the necessary deadening, and perhaps too much.

Obstructions should be avoided as much as possible. Columns for the support of balconies are often necessary, but should be made as thin as is consistent with the necessary strength; and many halls dispense with them altogether. But in addition to having the hall consist of one large open space, it is advisable for the auditorium to be so arranged that each seat may command an unobstructed view of the speaker or performer. This is more important for speech than for music, as a sight of the orator's face is often a help to comprehension; but it is advisable for all buildings for public use. The curve thus formed by successive rows of seats is called the isacoustic curve. It is not always necessary to make this curve rise by rows, as it may rise by groups of rows. Thus in Jordan Hall, Boston, the slope is such that the front rows are on a gentle incline, while those at the back are steeper; and the effect is excellent. Many Scotch churches, and a number of concert-halls, make use of this curve, though it has not been generally adopted by theatres. It is shown in the Roman amphitheatre at Nîmes. Chladni states that a better effect is obtained by having the stage low and the curve steep than by reversing these conditions, as sound seems to be delivered

best on a level (at least by voices), and is then most effectively diverted upward by the curving tier of seats.

Obstruction to sound occurs when it suddenly enters a narrow space, such as that below balconies. The seats in such cases should be made steeper, so that the sound will be entering the open end of a wedge, instead of traversing a passage with parallel sides; but the overhang of the gallery often prevents this. In such cases the under side of the floor of the gallery should slope down toward the back if possible. Obstruction also occurs when sound leaves a very confined space. Thus a noise made in a tunnel, near its end, will produce an echo from that end, even though it is open to the outer air. This, however, need cause the architect no worry, since the boxed-in stage is never constricted enough to produce such an effect.

Reverberation is an excess of resonance, that prolongs a sound and gives it a confused effect without actually producing an echo. The cause of this defect is sometimes rather hard to locate. It may arise from the proportions of the building, or from the materials used in its construction, or from hollow places outside the walls, floor or ceiling. It may even be due to a partial echo at close range. It is an excess of resonance, which is a good quality when present in proper amount. The best buildings for hearing are those that have a large amount of resonance, without quite reaching the point where reverberation begins. Unduly high halls, with continuous walls, are apt to show excessive reverberation. Large open spaces in the ceiling, such as deep recesses or skylight openings, seem to cause the same defect, and should be cut off from below by some interruption, or should have their sides tapered whenever possible, to avoid rectangular recesses. Dampness of the walls seems to be another cause of reverberation, so that new buildings may seem poor at first, though improving greatly after a few months. This is usually true of plastered walls. It has been possible in certain cases to conceal the walls with drapery until they have become thoroughly dry. The cause of the trouble is not very clear; but since seasoned wood gives better resonance than green wood, it is probable that the wet walls merely cause an echo, while after drying they vibrate in sympathy with the sound that strikes them, causing resonance without echo. Yet excessive resonance, as well as short-range smothered echo, is held to be a cause of reverberation, which would seem to contradict the above suggestion. Reverberation is allowable in buildings of the stock-exchange type, where noise is permissible; but it should be obviated elsewhere. The most successful case

of remedying reverberation by a slight change was at Exeter Hall, England, where a plain ceiling was substituted for one which was coffered, or inlaid with rectangular recesses.

The formation of echos depends upon principles readily understood, and therefore easily avoidable. It is only in large buildings that there is a chance for sound to be reflected directly, and this is usually caused by the wall farthest from the stage or rostrum. In smaller rooms an echo follows too closely on the original sound to be heard separately. It is possible to have echos caused by a ceiling, as in the reading room of the British-Museum. In that place, when it is not well filled, a sound in the middle will produce an echo from the dome, though, of course, this is not a serious defect in a room devoted to silence. In halls for speaking or singing, the ceiling echo, if present, is usually heard by the auditors at the rear.

The lower the ceiling, the less chance there is of its producing an echo. In cases where this defect is caused by a high ceiling, something must be interposed to check the effect. Thus at Coblentz, when a large law court, 46 feet high, was found to show echo, a cloth stretched below the top remedied the defect at once, and proved that the ceiling was the cause. Such a cloth, or velarium, is in use at Albert Hall, London, where it serves not only to prevent echo, but to cut off a large empty space that would deaden the sound by absorption.

In many good halls, the rear wall is made semicircular, or given some other form that is not a plain surface. If the wall is plane, the tendency to echo may be obviated by the use of many openings in it, or draperies over it, or columns before it. In some cases the erection of a balcony at the rear has been sufficient to diminish or destroy an echo. Sometimes more complex echos exist, due to the diagonal reflection of sound aroud a rectangular hall. In such cases, entrance doors are sometimes put in the corners. Another remedy is to do away with the sharp angles by substituting curved surfaces where walls or ceiling meet. The walls are usually plane, but the ceiling itself may be made in two slopes, or a curve, as well as having rounded sides. Symphony Hall, in Boston, has its ceiling rounded off at the edges.

A noted example of echo was found in one of the Back Bay churches of Boston, when the congregation first tested it. Every word of the preacher was duly repeated, producing an effect not in the least devotional. The owners finally sold the structure at a loss. The new congregation succeeded in overcoming the defect only after many trials, their experiments including the

building of a gallery, with the raising of the floor, and the stringing of many wires. When the same architect afterwards built Trinity Church, he was greeted with the remark: "I hear you have built a church where they can hear the preacher." Yet the architect was a famous exponent of his art, which goes to show that acoustics at that time was even more a *terra incognita* than at present.

Among the famous echoes of nature, it is said that Lake Killarney possesses a harmonic echo, returning an overtone instead of giving the original sound. If true (and some writers mention other instances) this may become another defect to which buildings could be liable, though the present writer has not yet heard of an instance.

Bad proportions may make a hall an acoustic failure, in addition to the defects already mentioned. Usually, however, the defect of unfavorable dimensions is reverberation; but other troubles may be caused. Thus if the height is greater than the breadth, absorption may take place, the sound filling the upper volumes at the expense of the lower. Great height also makes ceiling echoes possible. Undue width with too low a ceiling might cause reverberation, and would be apt to produce certain spots among the audience where the hearing would be confused. The best effect is obtained with the width about one and one half times the height. The length must of course be the largest dimension. A good effect is always produced by having the three dimensions proportional multiples of some given number. This is especially true of the width and hight. Thus in Free Trade Hall, at Manchester, England, the height is 52 feet, and the width 78 feet. The length, from the rear to the middle point of the recessed stage, is about 130 feet. This building is one of the best examples of good acoustics.

As an example of what to avoid in architectural acoustics, the Christian Science Temple, in Boston, may easily be awarded highest honors. The main part of its service-hall would be practically square by itself; but the height is too great in proportion, and the dome at the top causes a fairly noticeable echo. The side walls of this square, however, do not exist; for each side is rounded off in a large semicircle, topped by a half-dome. This makes the width much greater than the length. The back wall has a gallery, with supports that may divide the air into the vibrating spaces that produce reverberation; but the semicircular sides of the building cannot fail to cause this defect, since they carry a veritable network of arches and columns, rising in tiers, and extending all around the two curves. The reverberation of

these air spaces is so marked that the hearing is better and clearer a few feet outside of the doors than in the hall itself. The reader does the best that he can, by separating his syllables, and by giving them a long, sing-song effect, so that the reverberation and muffled echo from one syllable are not allowed to interfere much with the next; but the defects are still very noticeable.

Aids to good hearing in halls may be grouped under the two general heads of materials to obtain resonance, and reflectors of various sorts.

The use of sound-reflectors is widespread, and productive of excellent effects. This is necessarily true, since any reflector causing a bad effect is promptly and easily removed. A hard, polished surface is apt to produce a harsh effect, forming a too distinct echo that is not separate from the original sound, but produces an unpleasant effect. It is better to use resonant material rather than a reflecting surface, and slightly rough rather than smooth reflectors. The best material for this, as well as one of the cheapest, is wood.

Theoretically, a reflector shaped like a parabola seemed for many years the best form. The parabola is a curve so shaped that all lines reflected from a given point within it, called the focus, are parallel. Parabolic reflectors for light are used in automobile lamps and engine headlights. For reflecting sound, their most common use has been in churches, which always seem to present problems in architectural acoustics. A prominent example was a church at Attercliff, near Sheffield. When the preacher spoke first in the new building, there was a powerful resonance, but in spite of the resulting loudness, the words sounded unclear and confused. Changing the position of the pulpit proved unavailing, and nothing seemed to cause any improvement until the parabolic reflector was erected. This was hailed as a cure-all, and many other churches followed the example. But while this rendered the minister audible, the reflectors were soon found to have several defects. If the preacher moved about at all while talking, he would not always be in focus. But even in a fixed pulpit, trouble arose from the fact that the speaker could hear slight noises among the people, which were magnified by the reflector. He also heard a distinct and annoying echo of his own voice. Many of the reflectors, so popular at first, were afterwards torn down. At Attercliff, it was found that the original defects were less noticeable, probably because the plaster of the walls had had time to dry. Some churches had gone as

far as to build their walls in a parabolic shape; and they came to regret this procedure.

The parabolic reflector has been used to prevent sound. In the Berks County prison, in our own country, such reflectors have been introduced into the ventilating pipes, to prevent prisoners from communicating with one another. The sound is reflected back to its source in this case. Asbestos lining is often used to make walls sound-proof.

A plane reflector, inclined at an angle of from 20° to 30°, and sloping upward toward the audience, is now the most common form. Such a reflector cuts off some air space, and thus prevents absorption; it reflects sound directly toward the audience; and its material helps the tone by vibrating, as a sounding-board does in a piano.

The sympathetic vibration in any such material, whether in a sounding-board or in the wall, floor, or ceiling, adds to the resonance. This quality is sometimes obtained also by the intensifying power of the air itself. It may be helped by other devices; and where the ancients used resonating jars at various places in their public buildings, a modern authority has suggested the use of tubes of various sizes near the foot-lights of our theatres.

Almost all halls depend upon wooden linings for their resonance. The old ducal theatre at Parma, famous for its acoustics, was an early example. In this theatre a whisper from the stage could be heard anywhere in the auditorium. A more modern example is the hall of the Paris Conservatoire. The hall is stuffy and ill-ventilated, but the management is afraid to make any changes, lest the excellent acoustic qualities be destroyed.

The wooden linings for walls or ceiling, or the floor timbers, or the sounding-board, should all be thoroughly seasoned. The linings, and floor-boards, should be of uniform size, and as long as possible.

Empty spaces under the floor or above the ceiling have often proved excellent in increasing resonance. In European theatres and halls, especially in Italy, it has been customary to construct a hollow chamber below the stage. The value of this is shown by the case of the Teatro del Argentino, at Rome. When it became necessary to make the course of a canal run beneath the stage, the resulting air-space greatly improved the acoustics of the building.

That the ancient Romans were acquainted with the value of wooden construction is shown by a statement of Vitruvius. He advises the omission of the resonators used by the Greeks,

"since all public theatres built of wood have many floors, which are necessarily conductors of sound."

Wood is so cheap and so excellent a material that as yet no real substitutes for it are in use. For fireproof construction, however, thin metal plates have been suggested for use as room panels.

The excessive use of wooden linings may produce too much resonance, especially if the air-space of a hall is of such a form as to aid in the effect. But this is a fault that leans to virtue's side, for excessive resonance is very easily remedied. It must also be remembered that the presence of an audience helps to deaden the tone.

In dealing with air resonance, it might seem at first sight as if this would appear only on certain notes, in which cases the air would vibrate as a whole, or in fractional parts for overtones. That this is true to some extent is proved by the necessity for "voicing" such instruments as organs, or even pianos. The string, or pipe, that synchronizes with the vibration rate of the whole body of air will seem much louder than the others; and its power of tone must be lessened, to obviate this effect. But the example of the violin will show that it is possible for the semi-confined air, which must vibrate with the wood, to be set in motion at any vibration rate. In this way the air of certain buildings may help the speaker, no matter whether he pitches his voice high or low. But if he talks on the pitch of the entire air body, his voice, not "voiced" like the organ pipe mentioned above, will seem to gain greatly in power and resonance.

Good architects claim that the air resonates best when the dimensions of the building bear some simple relation to each other, as already illustrated by the figures given for Free Trade Hall. Under this condition the vibration rates for a certain overtone lengthwise will correspond with the rates of another overtone sidewise, and still another vertically. This reinforcement of overtones will add brilliancy to the speaker's voice, or the musical tone, and make it penetrate better.

Air currents are apt to interfere with the best transmission of sound. The slightest drift of air caused by an outside wind produces no important effect; but the currents due to heating have more influence. Some architects advise admitting the heat at the sides of the hall, and leavings openings between the balcony and the wall, through which the hot air may rise. It is also advisable to admit more than enough hot air from below, and at the same time allow the requisite amount of cold air to come in from above, through the roof.

Aerial resonance may sometimes be excessive; and this is probably the case in Canterbury Cathedral, where a note or chord is prolonged as if moving slowly around the walls of the edifice. While this effect may be beautiful in the slow passages of anthems, it interferes with the distinctness of the preacher's words, even if he talks slowly. For clearness in speaking, it is always advisable to diminish the air space as much as possible. Public halls may therefore be made low; while theatres should have area restricted, to make up for their great hight. The extensive balconies are thus an aid to hearing, except to those auditors who are hidden below.

The avoidance of the chief and most noticeable defects that have been enumerated has been considered sufficient by the architects of the past. But the fullest attention to all details is most necessary; for the difference between tolerable halls and good halls is most marked. The good hall necessitates no severe effort on the part of the speaker; while a poor edifice, such as a badly built church, will tax the speaker greatly, so that a preacher's life may be actually shortened by the work forced upon him by bad acoustical conditions.

The phenomenon of whispering galleries is one that always attracts attention. They result from the fact that various sound waves from one point are made to converge to another. This may be caused by direct reflection; but sometimes, as in St. Paul's and in the Capitol at Washington, it is caused by the waves following the wall around, close to the floor, instead of being wholly a reflection from the dome.

The very strong tendency of sound waves to follow curved surfaces is made use of in the Mormon Tabernacle at Salt Lake City. This edifice is shaped exactly like half an egg, cut lengthwise; and as a result the speaker is clearly audible in every part of the huge structure, which is probably the most successful building in the world, acoustically speaking.

Before any further mention of modern successes is made, it will be decidedly in place to give due praise to the ancient Greek theatres. The stage was backed by a wall, which formed an excellent reflector. The semicircular tiers of seats, up which the sound waves could travel, just as ocean waves wash up a slope, were practically in an isacoustic curve. To the good effect of all this was added the resonance of the Echeia, or hollow vessels. Under such favorable circumstances, it is no wonder that the Greek drama flourished. Even when the theatres were built of stone or marble instead of wood, the loss

of resonance was hardly noticed, resonance being at a minimum in open air.

It is a far cry from these amphitheatres to the ducal Theatre at Parma, which flourished in the sixteenth century, and fell into disuse only when the court left the city. Its form was oblong, with the back corners of the walls rounded off. It was 130 feet from the stage front to the rear wall; and the width was 102 feet. Calling the distance to a point near mid-stage 136 feet, the width and length were in the proportion of 3 to 4. Before the stage was an open space, from which the seats arose in a slant. The wooden boards of the walls were placed vertically instead of horizontally.

More directly derived from the Greek theatres are the semi-circular or semi-octagonal lecture rooms so common at our universities. These have their seats arranged on slopes that act like isacoustic curves; the roof is generally low rather than high; and the rise of the seats toward the ceiling makes the sound waves converge, and increases the hearing power in the rear.

The modern theatrical architect is confronted with several problems. The slope of the floor cannot be made as steep as it should be, though the floor could could often be given more of an isacoustic structure than it usually has, to avoid "dead" places. The balconies must have their upward slope, though their under sides should be made to slope downward if possible; tiers of boxes often injure the reflecting power of the side walls; ceiling echo must be avoided; and the absorption of the actor's voice, due to the large space on and above the stage, must be minimized. The actors always aid in the last point by keeping their faces toward the audience, and by speaking near the front of the stage. But even though the performers take these precautions, the scene should be "boxed in" as much as possible, even if the boxing is above the range of vision of the audience. In theatres, the relation of length to height, if correct at one spot, will be incorrect at others. It may be best made by taking the distance to the back of the first balcony in some proportion to the height. The seats under the first balcony, as already intimated, should be given more slope than the floor, if possible. The walls may be pear-shaped rather than semicircular, with the stage corresponding to the stem end, and the side walls straight. The ceiling is usually curved, and joins the walls with an obtuse angle if not an actual rounding. Sometimes the ceiling is made parallel to the floor. Walls nearly or wholly parallel, as in the Metropolitan Opera House, and the Parma theatre, will make it

possible to accommodate a larger number of auditors, the pear-shaped form being best for theatres of moderate size, with restricted sites. The Haymarket Theatre, in London, is an excellent example of this form, the back being slightly more than a semicircle, with straight side walls converging toward the stage. The stage itself is shallow, and extends forward into the house—a most excellent practice, in the present writer's opinion. The ceiling is curved down toward the stage, reflecting the sound excellently. The boxes are flat in front, so as to give partial aid in reflecting the sound. There are no columns. The walls in this theatre are lined with long lengths of thin wood. There are hollow spaces below the floor and above the ceiling. Originally the floor was isolated on strong frames; but that seemed to prevent it from resonating, and the floor is now given the customary structure, as an integral part of the building.

In view of all the difficulties in designing theatres, it is not surprising that many writers confine their attention wholly to this class of buildings.

Law courts form a much neglected class of edifices, from an acoustical point of view. In many cases they are little more than large rooms; but even in these, the proper structure would relieve judge and counsel of some effort. If reverberation is the trouble, as is usually the case, a gallery for draperies on the rare wall will often prove sufficient.

Concert-halls should be fairly easy to construct, in view of the rules now adopted by architects, and described in this article. Any hall that is all bad acoustically will probably be found to violate one or more of the principles enumerated. The dimensions (with length to the middle of the stage) should be multiples of some proportional number; the stage should be recessed, with a roof (or sounding board) rising at the proper angle as it extends forward; the ceiling should join the walls in a curve, and the back wall may join the sides in similar fashion; the ceiling (as also the walls) should not have any deep rectangular recesses; and the back wall should be diversified by a gallery, or entrance doors, or both; or it may be draped if necessary. The whole building should be lined with seasoned wood, in long pieces. There should be hollow spaces below the floor, or the stage, at any rate, and above the ceiling. Promenades outside the walls will have the same good effect. If necessary, the seats may be raised in the proper curve as their distance from the stage increases. Large halls should be oblong, but small ones may be built on the amphitheatre plan, with nearly semicircular auditorium and rising

seats. Symphony Hall and Jordan Hall, both in Boston, are excellent illustrations of the two types. Concert-halls on the half-egg principle are also excellent, Steinert Hall, in Boston, being an example.

The mediaeval cathedrals were chiefly intended for great choruses, or grand ceremonials. In these the music could fill all the air space, which was far too lofty for ordinary speaking. Such edifices, like that at Cologne, contained some small chapels for devotional purposes. But if it became necessary for the preacher to talk to a larger congregation in such a building, he generally had to have a sounding-board placed over him, with a group of pillars as backing. In such a case, as in all halls used for lectures, there will be a certain pitch of voice which will obtain the best effect, this pitch being evidently an overtone of the pitch to which the total mass of air corresponds. The enclosed air thus acts like the air in an organ pipe, which will vibrate to one fundamental pitch, or to any of the stronger overtones of that pitch. A speaker may thus gain gain clear and forcible tones with a minimum of effort, even in a large cathedral.

Churches built with a nave and aisles have often shown acoustical excellence. The nave, or long main body of the church, has its aisles marked off by rows of pillars. These divide the air into several small vibrating masses, which are easily set in motion. Sir Christopher Wren designed many excellent buildings of this sort.

Churches that have one large open space, instead of the nave-and-aisle structure, have seemed more apt to show acoustical defects. If the two sides of the roof are too nearly vertical, they form a sort of sound-destroying trench, and fail to give any helpful resonance, If they are smooth, they may cause too definite an echo or reverberation; so that it has become customary to let the roof timbers show. These defects seem to prove that the Gothic style, in spite of its large size, was based on correct principles, the groups of pillars dividing the air in a way to help the sound. The bad effect of steep roofs in the open church structure may be remedied by a rounded off polygonal ceiling placed some distance below the ridge-pole.

The use of iron in modern churches has enabled architects to call for columns without obstructing the view as much as formerly. The modern tendency, however, has been towards an open space, without columns. The architect of churches should be able to avoid the usual troubles, because he generally has a free hand in regard to area of site. Where a theatre is often

built on restricted ground, surrounded by other buildings, a church is usually placed on an extensive lot.

The position of the pulpit and lectern was formerly influenced by acoustical conditions. Many churches were found to be poor for speaking; and sometimes the defects were remedied by moving the pulpit out among the congregation. At present, with a recessed chancel, this is scarcely ever necessary. The chancel is built on much the same principle as the recessed stage in concert-halls.

The use of transepts has sometimes introduced defects. If the transept is made too deep, and any acoustical trouble arises, the defect may usually be remedied by galleries, or by anything that will make the transept shallow in proportion to its width.

If a gallery is used in the nave, it should be located on the back wall, where it will help to break up any echo effect.

The writer, when in the church of the First Parish in Brookline, has found that this edifice seems to combine many excellences. The chancel is recessed, with the back wall semicircular, and the top low in comparison with the main building. The pulpit and lectern are well in front, each a little to one side of the centre. The transepts, almost as far front as the pulpit itself, are only half as deep as they are wide. The main part of the church has no columns. At the back are three entrances, breaking up the end wall below, and a gallery above, for organ and choir. In this gallery are some of the larger organ pipes, which break the upper surface of the wall. The height to the ridge-pole is scarcely more than the width of the nave. The two sides of the roof slope at an angle of 45°, an excellent angle, which reflects the sound down toward the back of the church, and does so too quickly to cause reverberation. The sides of the roof are lined with wood, extra strips at short intervals breaking up the plane surface. The resonance from this is excellent. At the top of the walls (the base of the roof slopes) two or three tie-rods of iron, provided with turn buckles, neutralize the outer thrust of the roof. The tie-rods are held on each side by beams projecting inward. These beams and tie-rods are evidently sufficient to act as nodes, and let the air-space vibrate in an upper and lower half, instead of as a whole, thus requiring less effort from the speaker. The side walls are plane, with very shallow tapered recesses for the stained glass windows.

Architectural acoustics is not yet thoroughly mastered. If it were, then every modern building would be as perfect as the old Parma theatre. There is still much that is empirical, but

with the rules herein mentioned, and with the ever-present chance to imitate buildings that have shown acoustical excellence, no architect should go wholly wrong.